National Weather Service
Local-scale Numerical Weather Prediction
Planning Workshop

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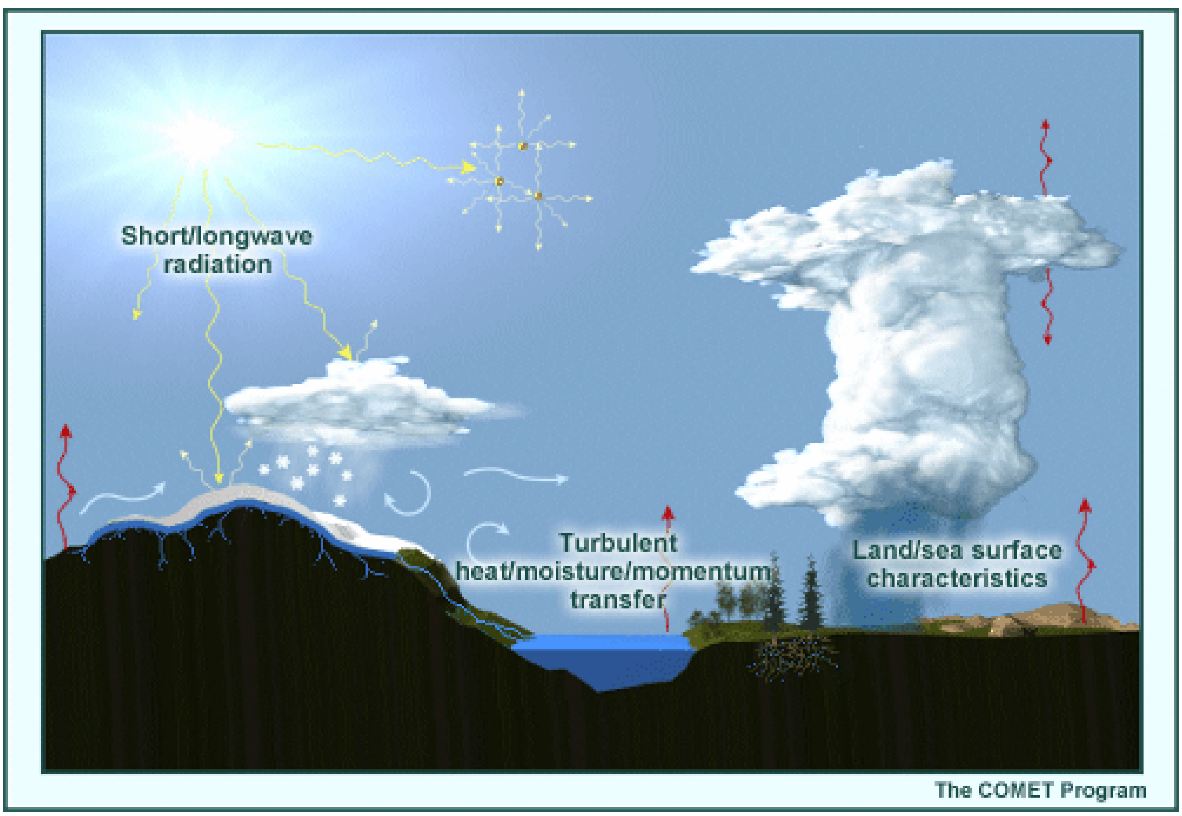

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Executive Summary

Currently, approximately 25 percent of National Weather Service (NWS) Weather Forecast Offices (WFOs) utilize some form of experimental, high-resolution numerical weather prediction (NWP) in their operations and/or training programs. In most cases, the models supporting this prediction are run locally on inexpensive Personal Computers. Generally, the WFOs using local-scale NWP (L-NWP) find the additional information provided by these models aides their forecast mission.

The Office of Science and Technology hosted a workshop in December 2000 focusing on formally integrating L-NWP into NWS operations. The workshop participants summarized ongoing experimental L-NWP applications in each NWS region and began to develop a roadmap for incorporating high-resolution models at the local Forecast Offices. They also identified the following list of potential benefits of an operational NWS L-NWP capability:

- More accurate specification (timing and location) of high impact, poorly forecast weather events including precipitation, clouds, visibility, winds, Terminal Area Forecast parameters (TAFS), and other parameters perturbed by local-scale forcings;
- Cost-effective support for the seamless suite of digital weather products at higher resolution and accuracy;
- More advantageous utilization of local data sets;
- A greater understanding of the meso/micro-scale aspects of the local atmosphere; and
- An improved mechanism for science and technology partnering and infusion.

Based on these benefits, the workshop participants agreed on the following vision:

All WFOs will be provided locally-optimized operational NWP output at spatial and temporal resolutions required to meet the NWS local warning and forecast, science and technology infusion goals.

To reach this vision, a configuration with two capabilities was proposed: one for daily operations and one for research and training. The recommended *operational* L-NWP system will run at all WFOs and River Forecast Centers (RFCs). It will at first utilize the workstation version of the Eta model initialized with regional analyses, but converge eventually to the Weather Research and Forecast (WRF) model initialized additionally with local data. This operational system will run 2-4 times/day with forecasts to at least 24 hours and produce full model resolution fields with sub-15 to 30 minute output available on AWIPS. This capability will be supported nationally necessitating minimal WFO maintenance. Training will be leveraged from current NWS/COMET programs. A second *research/training* system will have similar capabilities, but allow individual WFOs more flexibility to configure the model for local studies and training. Both capabilities will be run on a multiprocessor PC Linux system.

1. Introduction

Many National Weather Service (NWS) Weather Forecast Offices (WFOs) currently use experimental local applications of high-resolution (e.g., 10 km or less grid spacing) numerical weather prediction (NWP) models as an aide in their forecast operations and training programs. These applications consist of various hardware configurations and models run either at the individual WFO or in many cases, at universities or other cooperating organizations. Validation studies show that local-scale NWP (L-NWP) models capture severe hazardous storms and other small-scale phenomena not resolved by regional models such as those produced by the interaction between the synoptic flow and local terrain. There is also evidence that L-NWP information improves operational forecasts. This positive impact on NWS forecast operations along with the rapid advance of L-NWP in the 1990s, and the availability of affordable computer processing capabilities indicate that the time is right to move beyond experiment and more formally evaluate and plan for a uniform operational L-NWP capability at WFOs.

To lay the planning foundation for an operational L-NWP capability, the Office of Science and Technology (OST) hosted a workshop on NWS L-NWP in December 2000. The specific goal of the workshop was to develop a vision (Section 4) and roadmap (Section 6) for integrating L-NWP applications into NWS operations. In addition, the workshop participants summarized on-going experimental L-NWP activities in each NWS region (Section 2), evaluated the utility and benefits of these local modeling activities (Section 3), and drafted an operations concept for operational L-NWP at all WFOs.

2. Overview of L-NWP Activities

2.1 L-NWS at Forecast Offices

2.1.1 Survey Summary

Paul Hirschberg (OST) presented findings from a survey intended to quantify the extent and usefulness of L-NWP across the NWS. The survey questions were:

1) What is your WFO?

2) What is your Region?

3) Does your office utilize local model output in its warning and forecast operations ?

4) Does your office utilize local model output for training purposes, i.e., for retrospective studies, etc. ?

5) Where is the model run, your office, nearby university, etc.?

6) What model is used?

7) Is local data assimilated?

8) How do you display the data (AWIPS, independent box, etc.)?

9) Rate the usefulness of the local model information on a scale of 1 to 5 with 1 being not useful, 3 neutral, and 5 being very useful.

The major findings of the survey are as follows:

- 72% (87 out of 121) of WFOs responded to the survey.

- 49% (43 out of 87) of those WFOs responding use L-NWP output. 95% (41) of these 43 responded that they use L-NWP products in their forecasting operations, while 72% (31) of the 43 use L-NWP tools for training purposes.

- Of a total of 53 applications of L-NWP (some of the 43 offices use more than one) , 43% use models run at their office, 45% access L-NWP outputs from models run at local universities, 6% rely on NCEP L-NWP runs (e.g. the RSM), and 6% rely on the Air Force Weather Agency and other organizations for L-NWP execution.

- The majority (44%) of the WFO L-NWP applications utilize MM5, 36% use the workstation Eta, while the remaining 20% use RAMS, RSM, or some other model.

- Only 8% of the L-NWP applications use a local data assimilation system to initialize the model. The rest use the NCEP regional analyses and forecasts for initial and boundary conditions.

- 54% of the WFO L-NWP applications utilize N-AWIPS, AWIPS, or the Web to visualize L-NWP products. The remaining 46% utilize other methods such as NCAR graphics on Science Applications Computers (SAC), etc.

- The average rating on a scale of 1 (not useful) to 5 (very useful) of those WFOs utilizing L-NWP was 3.91 (useful). Not having the ability to display L-NWP products on AWIPS was the most significant reason that this average was not higher.

2.1.2 Specific Regional Activities

As the survey results above indicate, approximately 25% of WFOs are utilizing some form of experimental L-NWP.   Moreover, these enterprising efforts have arisen from WFO and Regional initiatives and without direct NWSHQ support aside from the COMET program. To understand these experimental L-NWP configurations more closely and to examine the best practices among these efforts, each regional workshop representative was asked to summarize the L-NWP activities in their regions by addressing the following topics:

- The number of offices utilizing L-NWP products.

- A summary of the efforts across the region including:
  - Modeling system(s) used
  - Model configurations
  - Hardware and communication systems
  - Operations Concepts including data assimilation, model run frequency, forecast range and run times and postprocessing features.
  - Accuracies
  - Utility and benefits
  - Costs
- Needs/Issues

The resulting Regional L-NWP information is summarized in Tables 1 and 2.

2.2 Developmental L-NWP Activities

2.2.1 NCEP/EMC

Geoff Dimego summarized NCEP's plans for developing and deploying work-station versions of their operational Eta Data Assimilation System (W-EDAS) and Eta models (W-Eta) for local-scale applications. Within the next several years, W-EDAS will include a 3-d variational assimilation system for local-scale initialization and W-Eta will have a non-hydrostatic physics option. By the 2004 timeframe, the W-EDAS and W-Eta will converge to the next-generation community weather Research and Forecast (WRF) modeling system discussed below. Although minimal direct WFO support for W-Eta is available from NCEP, the National SOO/SAC coordinator (Robert Rozumalski) supports much of the necessary model maintenance and upgrade requests from participating WFOs.

The grid spacings of the parent operational regional Eta model are expected to be reduced to 12 km and 60 levels by the end of 2001. This version will also include an assimilation of NexRAD radial velocities, GOES clouds, and precipitation. A tiled database access system has been demonstrated but not fully tested, which may allow the WFOs to access these high resolution datasets for L-NWP. In addition, NCEP plans to run a relocatable higher-resolution nested "Threats" model by the end of the year. Table 3 summarizes NCEP's seven-year regional modeling plan.

Table 1. Regional L-NWP Summaries

Region	WFO	Model	Config.	Hardware	Run-time	Utility
Eastern	OKX BUF/ BGM	MM5 MM5 w-eta	36/12/4k 2x/day 60/20 km 2x/day	4 proc DEC workstation dual P II	24- 48h 36 hrs	sea-breeze, coastal fronts, lake breezes, TAFS, weakly forced convection, ensembles, training
Southern (27 wfos)	typical	w-eta MM5	10-15 km 2x/day	dual PIII 800 MHz	24- 36h	warm season forecasts, availablity of non-std products
Central	typical	w-eta	10 km 2x/day	PIII 500mhz	36h	operational and training: lake-breeze, lake effect, convective initiation, upslope precip
Western (15 wfos)	eg: SLC TUS	Adas/ MM5 MM5	36/12/4k 2x/day 7 km 1x/day	PC linux clusters “	24h 24h	Research/Training: orographic forcing, convective boundaries, SREF
Alaska	3 wfos	MM5	45/12 km 2x/day	HP workstation dual PII	24 h	operations, research on exceptional events, unique local-scale phenomena
Pacific	HI	RSM	10 km 1x/day	run at NCEP	48h	terrain-driven flows, marine apps, gravity waves, on-site grids saves comms problems, 1.5 km research studies

Table 2. Regional L-NWP Summaries (cont.)

Region	WFO	Visualization	Evaluation	Cost	Needs/Issues
Eastern	OKX BUF/ BGM	AWIPS N-AWIPS, BUFKIT	underway MM5 value added >12h	student support Staff time, hardware	university support Comms for accessing BC data
South-ern	typical	w-eta: nawips MM5: awips	case studies	student support	Comms for accessing BC data, no FDDA, large output files
Central	typical	non-AWIPS	improved lake winds, Erratic in flat terrain	staff time, training	Faster comms for accessing BC, FDDA, faster hardware, objective verification, field support
Western	SLC TUS	AWIPS	case studies	Staff and training	Difficult to run accurately for operations, reliablity Man-power/skill levels vary
Alaskan	3 wfos	AWIPS	case studies	staff time, training	Faster hardware
Pacific	HI	AWIPS, VIS5d	seabreeze studies	minimal hardware	data sparse region

Table 3: NCEP's seven-year regional modeling plan.

Year:	**2001**	**2003**	**2005**	**2007**
Model	Eta	Eta/WRF	WRF	WRF
National (DX)	12	10	8	6
Threast (DX)	7	5	3	2

DiMego also summarized the community WRF model (http://www.wrf-model.org) and its application for L-NWP. The WRF will be able to address forecasting problems on the 1-10 km scale and is a collaborative effort among NCEP, the National Center for Atmospheric Research, the NOAA Office of Oceanic and Atmospheric Research, the National Science Foundation, the Federal Aviation Administration, and the Air Force Weather Agency. Several WRF teams have been charged to develop various aspects of the model, e.g., data assimilation, dynamics, physics, etc. NCEP is currently converting the existing Eta model into the WRF infrastructure so that accurate comparisons of computer and forecast performance can be evaluated. A complete research quality WRF model is expected by the end of FY2002 with NCEP operational implementation by FY2004.

2.2.2 NWS/OCWWS

Robert Rozumalski, NWS/OCWWS overviewed the support he provides to install and maintain the W-Eta at the WFOs. The model is simple to install on a host of Unix workstations and PCs and has been downloaded by 60 WFOs so far. The code is very efficient and scales very well on Symmetric Multi-Processor (SMP) systems. Version 2 to be released this year will include a non-hydrostatic option, with Eta and sigma coordinate systems and support for initialization with the NCEP regional model tile files. A transition to the WRF framework is expected within the next year. Rozumalski concluded with a summary of important mechanisms to consider when running a L-NWP: The primary forcing for local weather phenomena in the WFO area, the model execution time, computational domain needed, the initialization datasets and model physics required.

2.2.3 OAR/FSL

John McGinley highlighted the OAR Forecast System Laboratory's (FSL's) contribution to L-NWP viz a viz the Local Analysis and Prediction System (LAPS) and as a key developer of the WRF initialization and physics packages. FSL has been able to procure inexpensive workstations for L-NWP needs. A Kalman Filtering technique is under development in LAPS to provide much improved observational quality control and analyses. In addition, a LAPS water-in-all-phases analysis can provide additional cloud and cloud microphysical variables for initialization of L-NWP systems. FSL developed the static initialization system for WRF and expects to have a 3-D variational assimilation system for WRF by the end of FY 2001. The LAPS system also allows for a dynamically balanced, cloud-consistent L-NWP model hot-start, which can have a significant positive impact on short-term cloud and precipitation forecasts. FSL also is beginning to use L-NWP as part of a local-scale ensemble or consensus forecasting system.

3. Justification for Operational L-NWP

The consensus of the workshop participants was that the implementation of an operational L-NWP capability at each Field Office will enable NWS to reach 2005 Strategic Plan product and service goals by:

! Providing more accurate specification (timing and location) of high impact, poorly forecast weather events such as:

    < Precipitation and other sensible weather elements impacted by local terrain forcing caused by complex topography, land-water boundaries, etc ;

    < Thunderstorms, precipitation bands, and precipitation type. Such improvements will improve the lead time and accuracy of flash flood warnings in the 24 - 48 time period;

    < More precise predictions of TAF parameters such as clouds, cloud base and depth, and visibility thereby improving aviation forecasts accuracy and reducing false alarm rates; and

    < Increased accuracy of marine and coastal forcing of winds and waves by resolving coastal and estuarine features not resolved by regional models.

! Supporting the seamless suite of digital weather products at higher resolution and accuracy by extending centrally-produced NWP to locally-produced NWP at Field Offices.

! Utilizing local data sets more advantageously by ingest and assimilation into the model forecast.

! Increasing the understanding of the meso/micro-scale aspects of the local atmosphere by:

    < Visualizing the local atmosphere in 4-D
    < Developing and confirming conceptual models

! Broadening the conduit for Science and Technology infusion by:

    < Increasing opportunities for collaboration with the research community
    < Leveraging NWP systems expertise and knowledge across NWS
    < Training and education on NWP and local-scale phenomena
    < Injecting NWS experience with the community model back into research
    < Providing a broad testing environment for community model upgrades

4. Vision and Proposed system

On the basis of the discussion summarized in Section 3, the participants formed the following vision statement for NWS operational L-NWP:

> *All WFOs will be provided locally-optimized operational NWP output at spatial and temporal resolutions required to meet NWS local warning and forecast, and science and technology infusion goals.*

Next, the workshop participants broke up into three groups to put forward proposals for an operational L-NWP capability. Through a consensus-building process, the workshop participants discussed the pros and cons of each proposal and then developed a consensus hybrid proposal. This "Workshop Proposal" states that every WFO have two L-NWP capabilities: One operating in Standard "black box" configurations (Table 4) for daily operations and one for Research/Training applications (Table 5). For each of these capabilities, two configurations are proposed in Tables 4 and 5: A "Desired" configuration and a "Threshold" configuration. The latter would be the minimum configuration required to begin supporting operational L-NWP.

Table 4. Desired and Threshold Standard *Operational* L-NWP Configurations

Feature	**Desired**	**Threshold**
Location	At all WFOs and RFCs	"
Capability & access	All have access to a centrally-managed baseline capability	Produce timely operational L-NWP guidance at 2x the NCEP guidance resolution
Mode	Run baseline configuration that can be locally-adapted with minimal WFO maintenance and nationally supported	"
Model	W-eta converging to WRF	"
Init. & FDDA	Phased implementation from initialization with regional analysis to local data assimilation	Initialization with only regional analysis
Run freq.	4 times per day and/or event driven	4 times per day
Forecast	24 hrs or greater depending on situation	24 hrs
Postproc-essing	Full model resolution, sub- 15 minute output and visualization in GRIB, BUFR and NetCDF	Same as desired except 30 minute output
Derived Products	Full AWIPS Suite, sensible weather, L-MOS	AWIPS Suite
Display	AWIPS, D3D	AWIPS, D2D
Verificat-ion	national mesoscale metrics (including key forecast weather elements)	Current Eta metrics extended to TAF elements
Additional capabilities	full local grid and product archive. Backup plan	Initial and boundary condition and model version archive
System architec-ture	Redundant PC-based, LINUX OS, multi-processor system within AWIPS firewall. NCEP initialization grids delivered at full resolution	Hardware needed to meet above thresholds. NCEP initialization grids delivered at full resolution
Training	already covered under NWP PDS	"
Support (M+O)	99.9% reliablity, 24x7 support	95% reliablity, 8-5 M-F support

Table 5. Desired and Threshold Standard *Research* L-NWP Configurations

Feature	Desired	Threshold
Location	At the WFOs discretion	“
capability access	All have access to a centrally-managed baseline capability	“
Mode	WFO configured, operated and controlled. Also serves as a backup	“
Model	At the WFOs discretion	“
Initializat-ion and FDDA	WFOs discretion	“
Run frequency	WFOs discretion	less than 4 times/day
Forecast	WFOs discretion	24 hrs
Postproc-essing	Full model resolution, sub- 15 minute output and visualization in GRIB, BUFR and NetCDF	same as desired except 30 minute output
Derived Products	WFOs discretion	“
Display	WFOs discretion	“
Verificat-ion	WFOs discretion	
Additional capabilities	replays, ensembles, etc	“
System architec-ture	Redundant PC-based, LINUX OS, multi-processor system within AWIPS firewall. NCEP initialization grids delivered at full resolution	Hardware needed to meet above thresholds. NCEP initialization grids delivered at full resolution
Training	provide on-machine training	WFO optional
Support (M+O)	99.9% reliablity	95% reliablity

5. Challenges

Not surprisingly, several issues will have to be addressed as the Workshop Proposal is further detailed and an implementation plan for operational L-NWP is developed (Section 6):

Primary :

- Currently, AWIPS communications are not adequate to provide high-resolution NCEP regional model outputs to the local offices. Enhanced AWIPS or another means of communications should be explored.

- Additional WFO workload and training required by the implementation of L-NWP must be considered carefully and minimized.

Secondary, once L-NWP systems are implemented:

- The NWS requirement for uniformity of services between WFOs must be met. Therefore, L-NWP coordination will be needed between adjacent WFOs.

- New techniques for objective and precipitation verification at the local-scale are needed.

- The extent and scope of a change management plan for L-NWP is required.

- The impact L-NWP will have on the OST/MDL National Digital Database (NDD) program is unclear. Further coordination with MDL is needed to provide a method for implementation of new localized L-NWP products into the NDD.

6. Roadmap

The following is the roadmap (necessary steps) to bring the Workshop Proposal for an operational L-NWP to maturity in the form of a Corporate Board Implementation. Science Plans Brance (SPB) and/or Programs Management Branch (PMB) would be responsible for deliverables.

Milestones	Organization	Due Date
! Workshop Report	OST/SPB	2/1/01
! Charge NP Team	OST/SPB	2/9/01
! 2nd Draft L-NWP Proposal (costs included)	OST/SPB	3/10/01
! Investment Review Board Approval	OST/SPB	3/15/01
! FY 03 Initiative (if necessary)	OST/SPB	3/15/01
! Corporate Board Approval	OST/SPB	3/31/01
! Implementation plan	OST/SPB/PMB	6/15/01
! Begin Implementation	OST/PMB	7/15/01

7. Conclusions

Recent advances in affordable PC-based computing technology and the continuing sophistication of high-resolution models have allowed many WFOs to begin experimenting with high-resolution L-NWP. In particular, non-hydrostatic (<10 km grid spacings) model simulations have been able to consistently identify terrain-driven flows often critical to local forecast problems. In addition, these models are often run on relatively inexpensive computers that can deliver a 24 hour forecast in under 2 hours of clock time. The Workshop participants all agreed that the time is right to move this L-NWP experimental capability at many WFOs to an operationally capability allowing all WFOs access to local model guidance.